Solution 7.1

Hot liquid sodium at 400°C flows through a solid plutonium pipe, also at 400°C. Naturally, one should worry about the amount of plutonium that can be dissolved in liquid sodium. Assume that the system is at 1 atm pressure and that the sodium is virtually insoluble in solid plutonium; but, plutonium forms an ideal solution with liquid sodium. Find a thermodynamic estimate of the maximum composition of plutonium in the liquid sodium.

Sodium is virtually insoluble in solid plutonium - this shows

\[
\begin{align*}
\mu_{solid}^\text{plutonium} & = \mu_{solid}^\text{plutonium,0} + RT\ln X_{plutonium}^\text{solid} \\
\tilde{G}_{solid}^\text{plutonium} & = \tilde{G}_{solid}^\text{plutonium,0}
\end{align*}
\]

where \(\tilde{G}_{\text{plutonium,0}}\) is the reference state. However with sodium, liquid forms ideal solution,

\[
\begin{align*}
\mu_{\text{liquid}}^\text{plutonium} & = \mu_{\text{liquid}}^\text{plutonium,0} + RT\ln X_{\text{plutonium}}^\text{liquid} \\
\tilde{G}_{\text{liquid}}^\text{plutonium} & = \tilde{G}_{\text{liquid}}^\text{plutonium,0} + RT\ln X_{\text{plutonium}}^\text{liquid}
\end{align*}
\]

For the equilibrium, \(\mu_{\text{liquid}}^\text{plutonium} = \mu_{\text{liquid}}^\text{plutonium,0}\) or \(\tilde{G}_{\text{liquid}}^\text{plutonium} = \tilde{G}_{\text{liquid}}^\text{plutonium,0}\). This leads to,

\[
\tilde{G}_{\text{liquid}}^\text{plutonium,0} - \tilde{G}_{\text{solid}}^\text{plutonium,0} = RT\ln X_{\text{plutonium}}^\text{*}
\]

where \(X_{\text{plutonium}}^\text{*}\) is the equilibrium composition.

This quantity \(\Delta G_0 = \tilde{G}_{\text{liquid}}^\text{plutonium,0} - \tilde{G}_{\text{solid}}^\text{plutonium,0}\) at 400°C can be obtained from Problem Set 5.1. \(\tilde{G}_{\text{plutonium,0}} = \tilde{G}_{\text{plutonium,0}}^\gamma = -10138\text{cal/mole}\). Extrapolating the expressions for \(\tilde{G}_{\text{plutonium,0}}\) and \(\tilde{G}_{\text{plutonium,0}}\) down to 673K gives \(\tilde{G}_{\text{plutonium,0}} = -10089\text{cal/mole}\).

Using \(\Delta G_0 = 49\text{cal/mole}\) at 673K, the equilibrium concentration \(X^*\) can be calculated as

\[
X^* = \exp(-\Delta G_0/(RT)) = \exp\left[\frac{-49}{1.987 \cdot 673}\right] = 0.964
\]

Therefore, almost all of the liquid is plutonium and only a small fraction, less than 5%, is sodium.